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ELECTROGONIOMETRIC STUDY OF LOCOMOTION AND OF SOME ATHLETIC MOVEMENTS

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TABLE OF CONTENTS

Introduction

In a previous report,[1] it was shown that elgons could be used to study the action of the leg during walking. The present report deals with the analysis of the action of the knee and ankle joints during walking on the treadmill with various angles of inclination. An attempt was also made to analyze the action of the same joints during running, somersaulting, and swimming. The action of the elbow joint was also studied in pitching a baseball, in shot putting, and in swimming.

Materials and Method

The equipment used in this study was essentially the same described previously,[1] with the exception of a redesigned elgon for the knee and elbow, and also a waterproof elgon, which is still in process of development.

Elgons. Fig. 1 illustrates the changes in the elgon. The tubular shafts attached to the potentiometer have been eliminated and shorter arms, with studs at the ends, have been substituted. With these studs, the potentiometer is attached to the chassis. The chassis has also been modified and hinges were placed on each side of the potentiometer. Without these hinges, the potentiometer used to snap out of the central socket, especially when the outer side of the legs formed an inward angle at the knee, either because of genu valgum or because of bulky muscles in some athletes.

To adapt an elgon for use in swimming, it was waterproofed. This was done by covering the potentiometer with Araldite Epoxy Resin

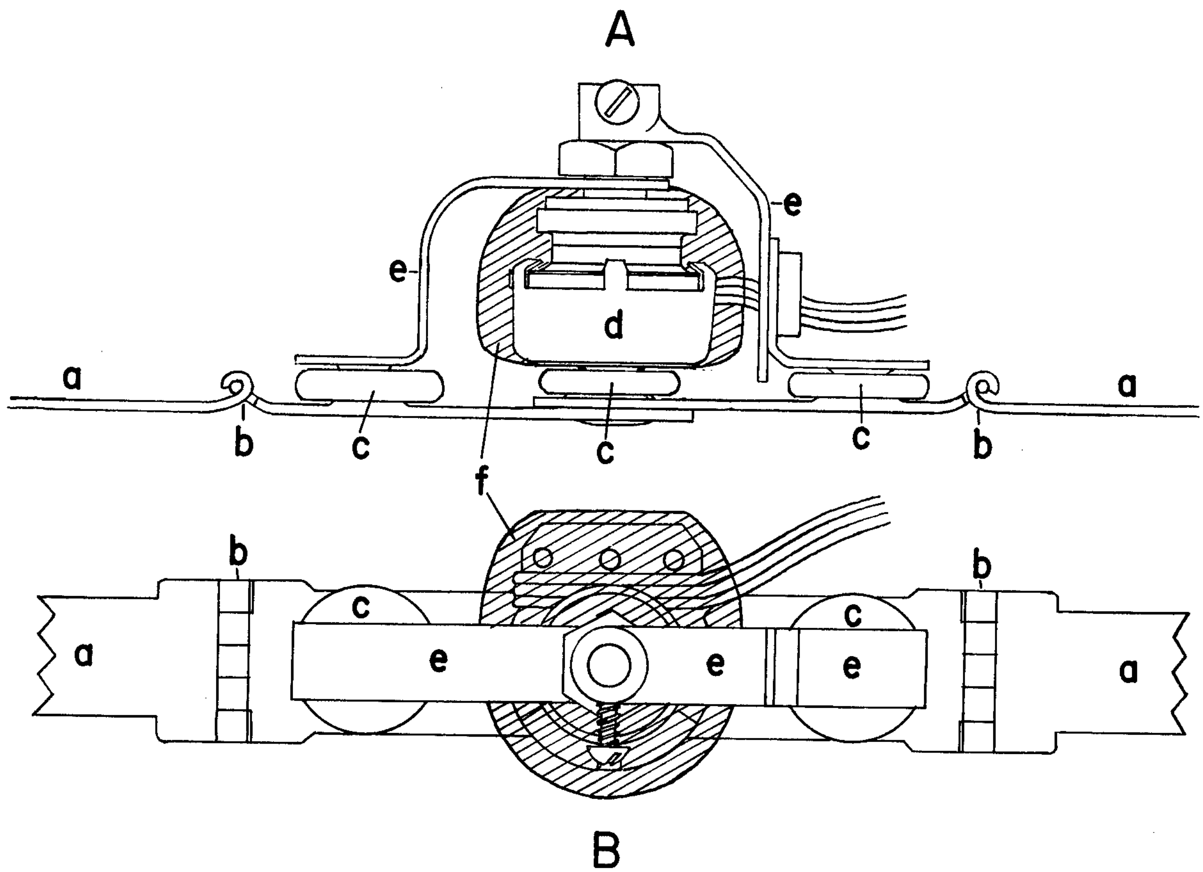

Fig. 1. Modified elgon. A, side view, and B, top view. a, chassis; b, hinge; c, receptacles for snap buttons soldered to the chassis for holding the potentiometer d; e, potentiometer arms; f, resin for waterproofing potentiometer.

Product No. 502 and Araldite Epoxy Resin Hardener No. 951 (both manufactured by CIBA) in 10:1 weight ratio. The lead wires, coming from the potentiometer, are encased in plastic tubing, which extends into the resin. The only part of the potentiometer accessible to water is a small space around the base of the shaft. To seal this space, a tight fitting rubber washer, coated with petroleum jelly, was pressed firmly down to the bar of the shaft where it emerges from the potentiometer.

Although this elgon works well under water, this base of the shaft is an Achilles' heel, and better waterproofing will have to be developed.

Walking. All walking was done on an electrically operated treadmill. Walking speeds were 2.5 and 3.0 m.p.h. and the inclination of the walking surface was 0°, $+5^\circ$, $+10^\circ$, -5°, and -10°. The plus sign indicates that walking was done uphill while the minus sign indicates downhill walking.

When it was desired to have the subject walk at a certain number of steps per minute (100, 120, and 138), the cadence was set by a metronome.

Running. Running was done on a horizontal plane at 5.0 m.p.h. at natural cadence.

Swimming. In recording swimming strokes over the length of the pool, the recording equipment was located at the midpoint of one side of the pool with enough lead wire attached to the elgon to reach slightly over half the pool length. The subject then started

at one end of the pool and swam to the other end with one experimenter walking along on the edge of the pool to keep the lead wires straight.

Points of Reference. For the purpose of analysis of goniograms, it was necessary to establish some reference points, which could be automatically marked on the record. These points were as follows:

A. Walking. 1, heel contact with the ground; and 2, toe lift (the instant the toe loses contact with the ground).

B. Running. 1, foot contact with the ground; and 2, toe lift.

C. Sprint start. The instant when the right and left foot leave the starting blocks.

D. Baseball and shot putting. The instant when the ball or the shot are released from the hand.

In walking, three methods were used to record the moment of heel contact and the toe lift. One method involved covering the treadmill belt with aluminum foil. Similarly, aluminum foil was placed on the sole of the foot. The subject and the foil on the belt were put in the same electric circuit. The contact between the foil and the rest of the circuit was maintained by aluminum foil strips made into a loose bunch secured to the frame of the treadmill, with the free end resting on the conveyor belt. With this arrangement, when the heel touched the foil the circuit was closed, and when the toe was lifted the circuit was broken. While this method gave accurate results, it suffered from the disadvantage that the aluminum foil did not stand up too well under use and had

to be mended frequently.

The second method consisted of placing special switches on the heel and the toe. Several types of switches were used. One consisted of a small length of rubber tubing with two strips of paper backed with aluminum foil glued inside, lengthwise and opposite to each other. A slight pressure flattened the tubing, caused contact between the two pieces of foil and closed the circuit. When pressure was relieved, the tubing regained its original shape and the circuit was broken.

Another modification of the switch was made of two thin pieces of steel, $\frac{1}{4}$" wide and 1" long, placed one on top of the other but separated at both ends by two layers of black insulating tape. A slight pressure resulted in a contact at the middle of the two springs which closed the circuit.

To record the moment at which the right and the left foot left the starting block during the sprint start, two strips of aluminum foil were placed an eighth of an inch apart on the front surface of the blocks, and the toes of the shoes were also covered with aluminum foil. When the feet were on the block, the circuits were closed. When a foot left the block, the corresponding circuit was broken.

To determine the moment of release of the baseball or of the shot, aluminum foil was placed on that part of the ball and the shot which was held in the hand grip. Fine flexible wires were placed on the throwing fingers. When the ball or the shot was held in the hand, the circuit was closed; when it was released, the circuit was

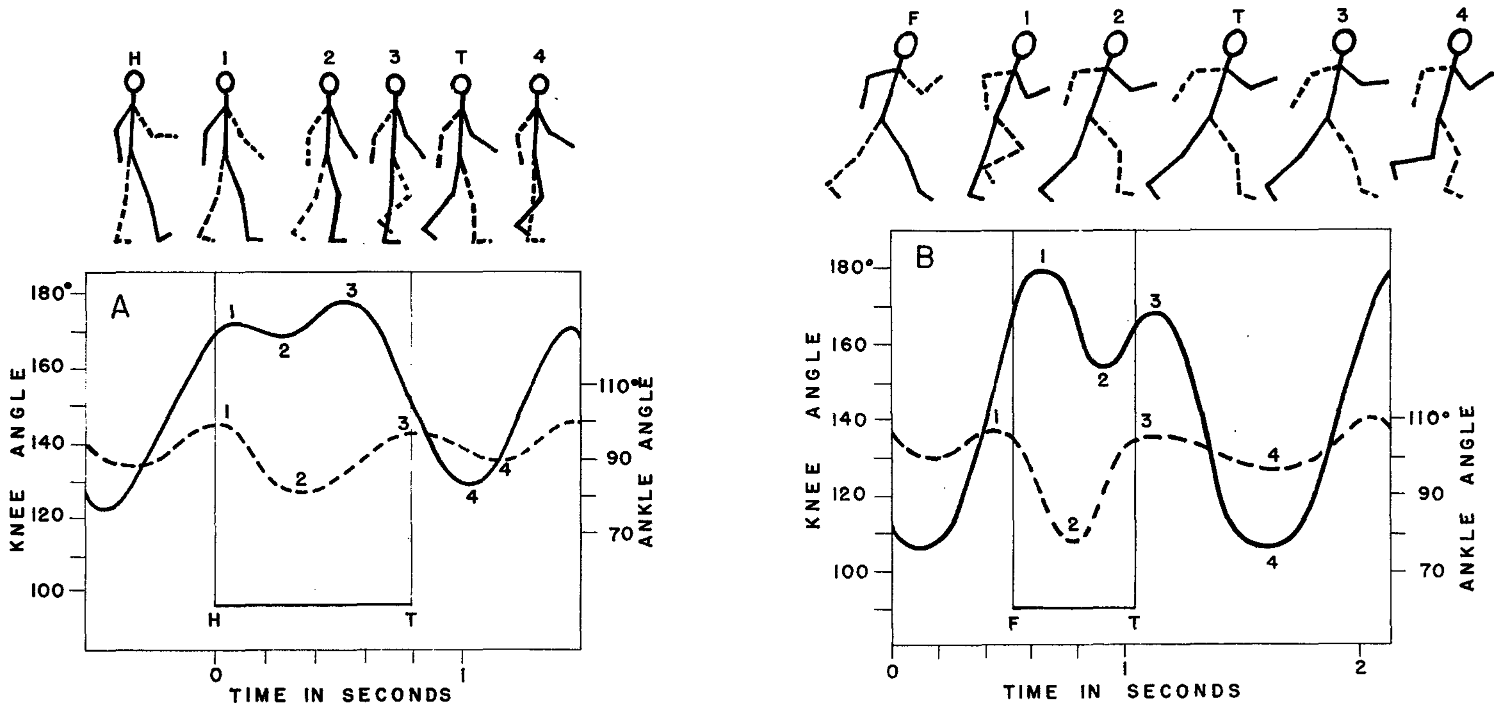

Fig. 2. Goniograms of right knee and right ankle in walking and running. Solid line, knee; broken line, ankle. A, walking on horizontal, 2.5 m.p.h. and 120 steps per minute. B, running on horizontal at 5.0 m.p.h. with natural cadence. Reference points: H, heel contact (F, foot contact in running); T, toe lift. Knee: 1, first extension; 2, shock absorption; 3, second extension; and 4, greatest flexion. Ankle: 1, first extension; 2, flexion during support phase; 3, second extension; and 4, flexion during swing phase.

broken.

Results and Discussion

In order to facilitate the use of reference points, Fig. 2 was prepared. It may be seen that points 1, 2, 3, and 4 are located on approximately similar elevations or depressions in both goniograms for walking and running. However, their relation to the support and swing phase is different. In walking, points 1, 2, and 3 occur during the stance phase while in running, only points 1 and 2 on the knee goniogram and only point 2 of the ankle goniogram occur during the support phase. These reference points will be identified as follows: Knee: 1, first extension; 2, flexion during stance or shock absorption; 3, second extension; and 4, flexion during swing phase. Ankle: 1, first extension; 2, flexion during support phase; 3, second extension; and 4, flexion during swing phase.

In walking, when the foot is placed on the ground a heel contact results (marked with a letter H on the goniogram). In running, the heel contact is absent because the foot is placed on its ball (at the moment indicated by a letter F).

A group of typical goniograms obtained during walking on the horizontal plane, upgrade and downgrade, is shown in Fig. 3. A goniogram of running on the horizontal plane is also given. An examination of the knee goniograms reveals that the relative positions of points 1 and 2 can easily identify the inclination of the supporting surface. When walking was done on the horizontal plane, the heights of the points 1 and 2 are about equal. When walking is done upgrade,

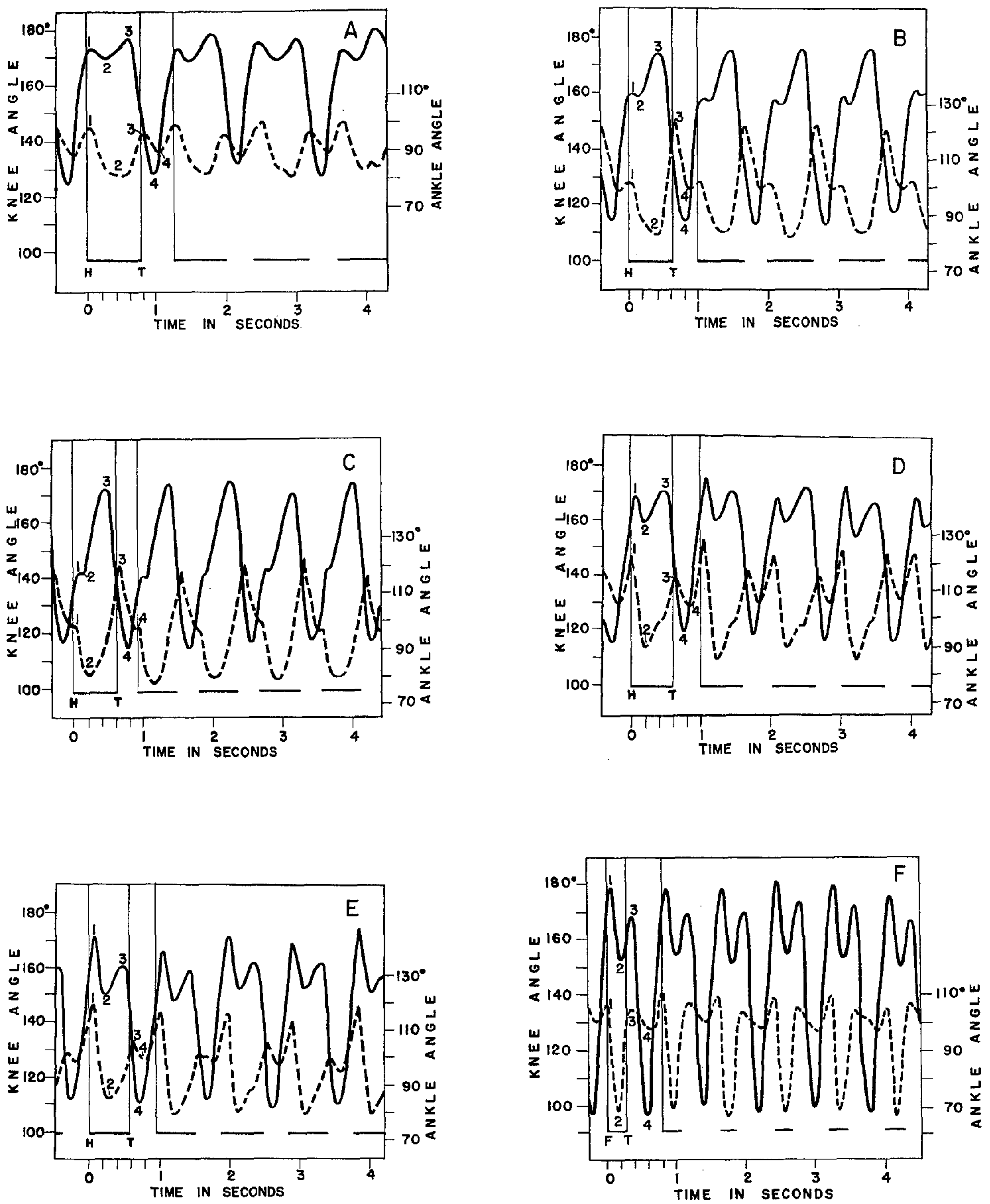

Fig. 3. Goniograms of walking and running. Walking at 3.0 m.p.h., 120 steps per minute and at various inclinations: A, horizontal; B, 5° upgrade; C, 10° upgrade; D, 5° downgrade; E, 10° downgrade; F, running on the horizontal at 5.0 m.p.h. without controlled cadence. Reference points: H, heel contact; T, toe lift. Knee: 1, first extension; 2, shock absorption; 3, second extension; and 4, greatest flexion. Ankle: 1, first extension; 2, flexion during support phase; 3, second extension; and 4, flexion during swing phase. Bars indicate support phase and spaces between bars indicate swing phase.

F, in the last graph, represents foot contact.

the point 2 is higher than the point 1. When walking is done downgrade, the position is reversed and the point 2 is lower than the point 1.

For identification of the ankle goniograms, special attention should be paid to points 1 and 3. If they are at the same height, walking was done on the horizontal plane; when 3 is higher than 1, walking was done upgrade; and when point 3 is lower than 1, walking was done downgrade. Since running was done only on the horizontal plane, no analysis similar to that made on goniograms of walking can be made at this time. One may observe, however, that the goniogram of running on the horizontal plane looks somewhat like the goniogram of walking downgrade. The mean data obtained on seven subjects in walking are given in Tables 1 and 2.

<u>Effect of the step length upon the knee angle</u>. The length of the step was determined by dividing the distance covered in one minute by the cadence.

	Step length in inches	
Cadence	2.5 m.p.h.	3.0 m.p.h.
100	26.4	
120	22.0	26.4
138	19.1	23.0

An examination of Tables 1 & 2 show that when walking was done on the honrizontal plane, longer steps caused an increase in size of the angles at all reference points except point 3. This relationship remained to some extent when walking was done upgrade. The effect was noticeable when the steps differed by 7.3 inches, but when the difference was less than four inches, the effect was some-

times absent.

In walking downgrade, the relation between the step length and the knee angle was reversed; that is, with an increase in step length the knee angles decreased. This was noticeable even at the point 3 and especially at the point 2. There was no difference, however, between the angles at the heel contact and also at the point 1.

<u>Effect of step length upon the ankle angle</u>. With the increase in the step length there was a tendency for an increase in the ankle angle at various reference points even during a downgrade walking. The difference, however, was very slight, just a few degrees if any.

<u>Effect of the grade upon the knee angle</u>. In walking upgrade, the knee is flexed more than in walking on the horizontal plane. This is true for all the reference points except point 4 and at the toe lift. When the heel contacts the ground, the angle is reduced by 20 degrees and by 24 degrees at the point 1. At the points 3, 4, and toe lift, the angles are practically the same as in walking on the horizontal plane.

In walking downgrade, the leg is more extended when the heel contacts the ground (8 degrees) and it is still five degrees greater at the point 1; but then it becomes smaller at the points 2, 3, and 4, and especially at the toe lift when the knee angle is 17 degrees smaller than on the horizontal plane.

<u>Effect of grade walking upon the ankle angle</u>. In upgrade and downgrade walking, the relation between the grade and the size of the ankle angle is similar to that in the knee joint. In downgrade

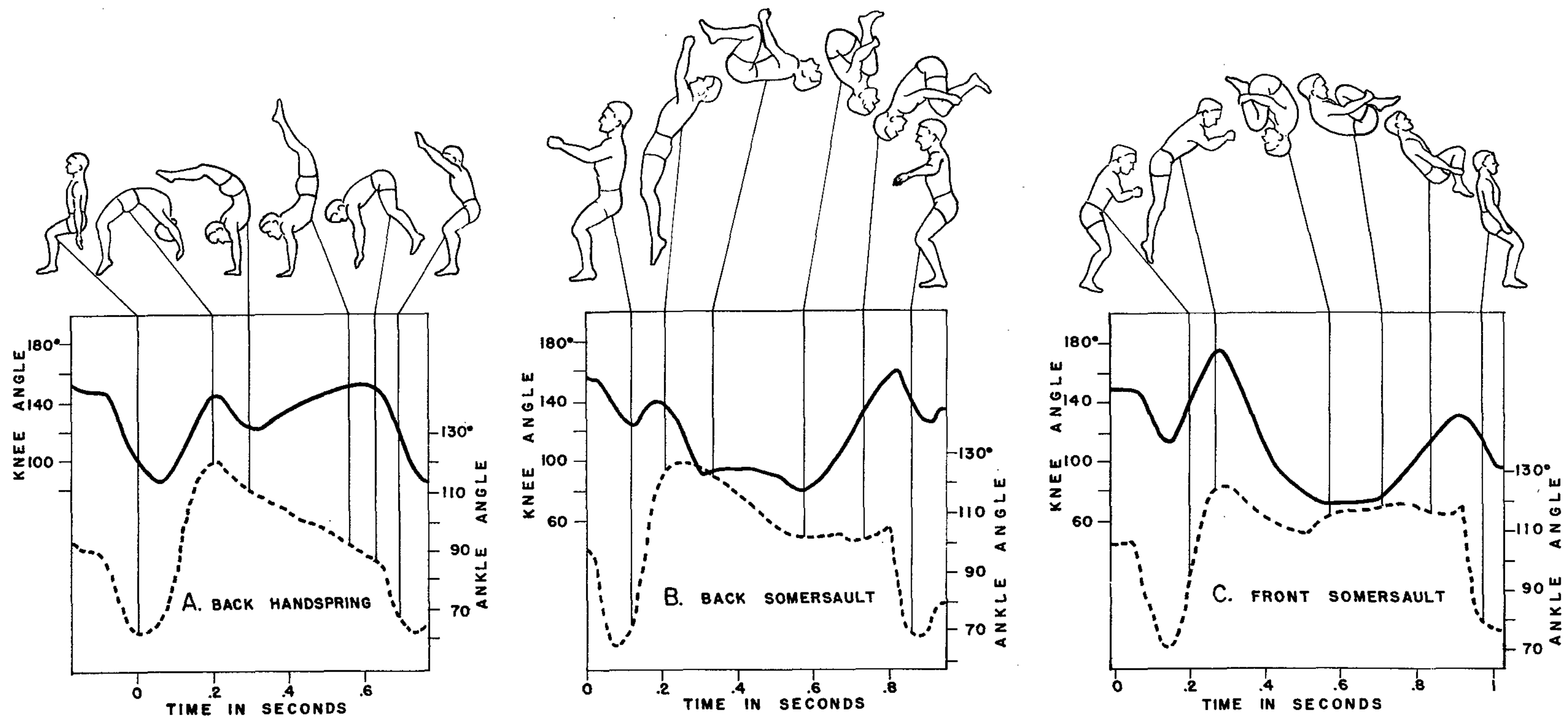

Fig. 4. Goniograms of tumbling. Solid line, right knee; broken line, right ankle. A, back handspring; B, back somersault; and C, front somersault. (Human figures redrawn from William R. Laporte & Al. G. Renner, The Tumbler's Manual, (C)1938. Prentice-Hall, Inc., Englewood Cliffs, N. J. Reprinted by permission).

walking, the angle is greater than in walking on the horizontal plane at the heel contact, toe lift, and the points 1 and 4, but it is smaller at the points 2 and 3.

In downgrade walking, when the heel touches the ground, the ankle is flexed seven degrees more than on the horizontal plane. The ankle is flexed more at all the points except the toe lift when it is extended slightly.

Athletic Movements

Tumbling. Hitherto, analysis of the position of limbs during tumbling was possible only by means of either movies or stroboscopic photographs. In this study an attempt was made to use the knee and ankle elgons for this purpose. The stunts selected for the investigation were back handspring, back somersault, and front somersault performed by a well trained instructor of tumbling. Three typical goniograms of these stunts are given in Fig. 4. The line drawings of an acrobat were taken from a well-known text on tumbling by Laporte and Renner.[2] Comparison of the knee and ankle angles on the drawings with those on goniograms shows a good agreement with one exception. Instructors of tumbling coach their pupils to extend toes during the flight through the air. This is well shown on the drawings of the man. An examination of the goniogram A shows that in the back handspring the toes are extended only at the beginning of the flight, after which the feet are gradually dorsiflexed. Further tests are necessary in order to clarify this apparent discrepancy. It is planned to continue the study of tumbling using elgons for the other

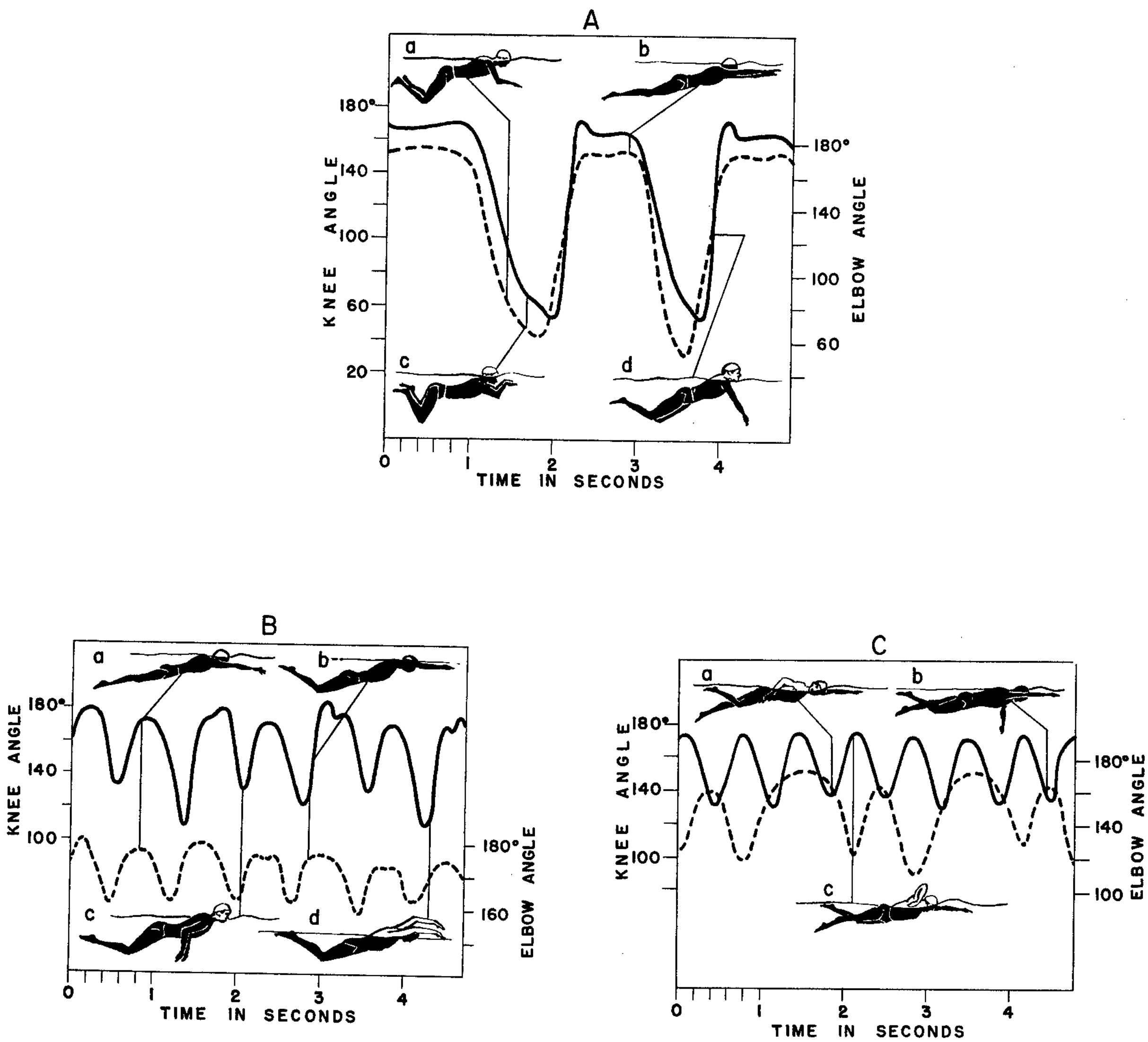

Fig. 5. Goniograms of swimming. Solid line, right knee; broken line, right elbow. A, breast stroke; B, dolphin-butterfly; and C, crawl. (Human figures after M. Madders, Swimming and Swimming Strokes, ©1957. Educational Productions LTD, and Amateur Swimming Association, London. Reprinted by permission).

joints.

Swimming. There is a great deal of arguing among swimming coaches regarding the relative position of the arms and legs during various phases of different strokes. Analysis of motion pictures supplies only a partial answer because a three dimensional movement cannot be accurately reproduced on a two dimensional photograph. With the development of a waterproof elgon an attempt was made to measure the angles made by the knee and the elbow during various swimming strokes: breast, dolphin-butterfly, and crawl. Three goniograms are given in Fig. 5.

In the breast stroke, A, there is a certain parallelism in changes of both angles. The range of movement for both knee and elbow joints is the same, 120 degrees, varying from 50-55 to 170-175 degrees respectively.

In the dolphin-butterfly stroke, B, this parallelism is preserved but the angle ranges are greatly reduced, 60 degrees for the knee (120-180) and 15 degrees for the elbow (160-175). One may observe a close relation between the goniograms and angles in the drawings of a swimmer, taken from a popular English text, Swimming and Swimming Strokes, by Madders.[3]

In the crawl stroke, C, there were obviously more leg kicks than arm pulls. The knee angles had a range smaller than in the two other strokes, 45 degrees (130-175). The elbow angles range was 50 degrees (120-170), much less than in the breast stroke, but almost three times greater than in the butterfly. In the crawl stroke one

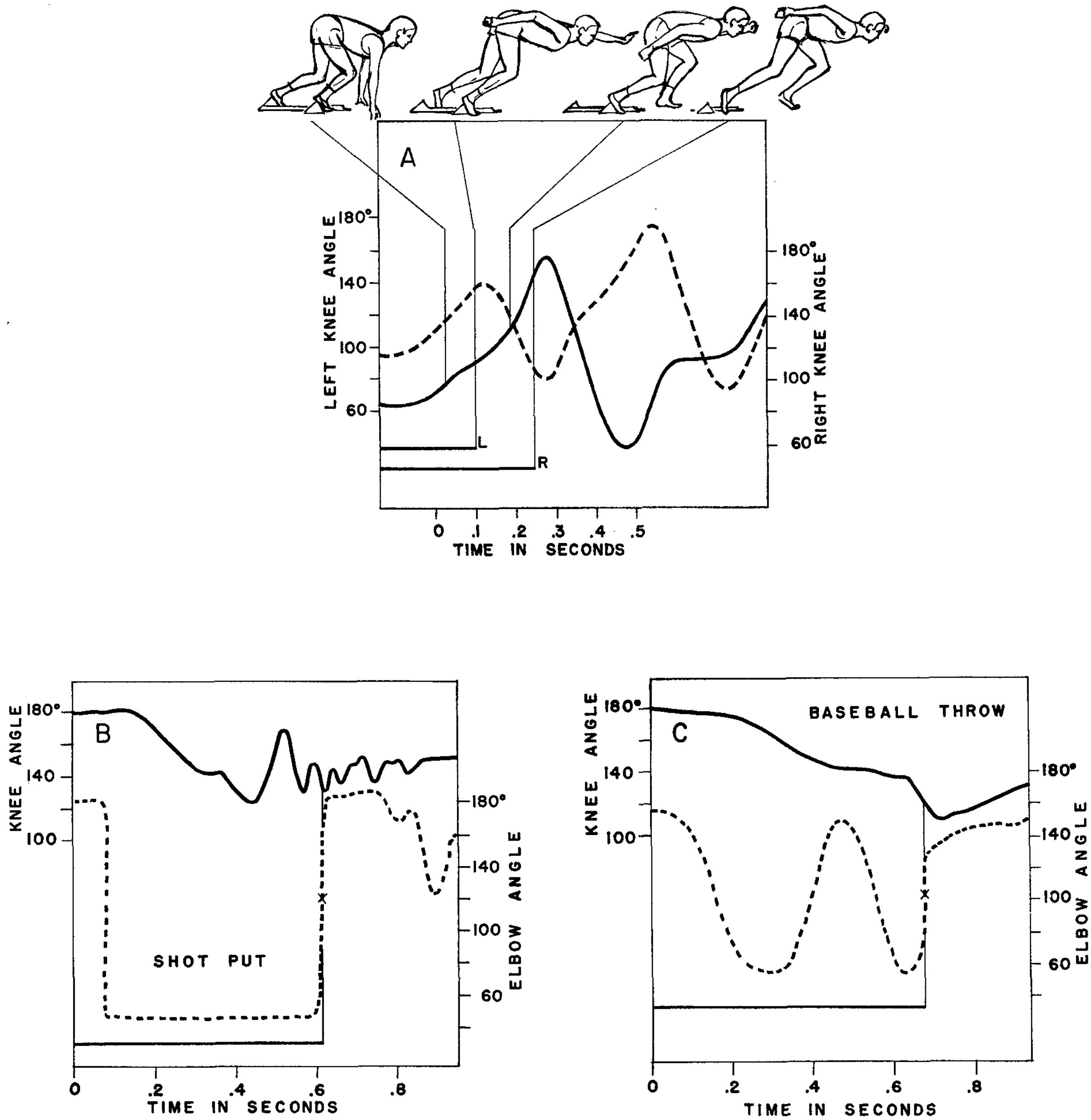

Fig. 6. Goniograms of sprint start, shot put, and baseball throw. A, sprint start; solid line, right knee; broken line, left knee; (L, left foot leaving block; and R, right foot leaving block). B, shot put; solid line, right knee; broken line, right elbow; (X, moment of release). C, baseball throw; (X, moment of release).

may observe an alternation in the duration of the arm pull. The longer elbow pulls correspond to the inhalation made by the swimmer who took a breath during every other right arm pull.

Although the waterproof elgon needs further improvements, it undoubtedly can be used for recording movements of joints under water.

Sprint Start. Two elgons were used, one on each knee. The subject was a good sprinter, In the starting position he used his right leg as the drive leg. (The foot of the drive leg leaves the starting block last). From Fig. 6 A, it may be seen that when the left foot left the block, the knee angle of the corresponding leg was 134 degrees. When the right foot left the block, the angle of the right knee was 140 degrees. Thus, during the take-off neither leg is straight, a misconcept held by many runners. It may be seen that the foot of the drive leg left the block 0.24 second after the back leg.

Shot-put. Fig. 6 B shows that the elbow,angle during the moment of release of the shot was 120 degrees and not 180 as some performers are inclined to think. The knee joint at the same moment was 138 degrees.

Baseball Throw. At the moment of the ball release, the elbow was at a 102 degrees angle, and not straight as again laymen are inclined to think. A release of the ball from a straight arm would result in many serious elbow injuries because it takes some distance to stop the motion of a fast moving arm. The 80 degrees of the unused amplitude provide sufficient angular distance to break the

action gradually. The angle of the knee joint at the moment of release was 65 degrees. Thus, elgons can be used in the analysis of various athletic activities.

Conclusion

Elgons provide a convenient and sometimes the only means of recording movements in joints during various activities on land and in water.

We want to acknowledge the invaluable assistance given by Mr. George P. Karpovich, who developed the new modification of the elgon and also adapted it for use in water.

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TABLE 1. EFFECT OF CADENCE AND INCLINATION ON KNEE ANGLES AT SELECTED POINTS IN WALKING. SEVEN SUBJECTS.

A. Speed 2.5 m.p.h.

Cadence	Grade, Degrees	Reference Points: Heel Contact	1	2	3	Toe Lift	4
100	0	164 ± 2.5	171 ± 3.1	166 ± 3.0	176 ± 2.1	155 ± 1.7	120 ± 2.0
	5	156 ± 3.0	162 ± 2.9	156 ± 1.3	175 ± 1.2	154 ± 2.3	119 ± 2.0
	10	141 ± 2.6	146 ± 2.5	143 ± 2.8	177 ± 1.6	159 ± 1.5	121 ± 2.6
	-5	165 ± 1.9	174 ± 1.3	161 ± 2.2	172 ± 2.1	157 ± 2.8	115 ± 2.2
	-10	166 ± 1.1	171 ± 1.6	149 ± 2.1	155 ± 2.2	134 ± 1.7	110 ± 1.6
120	0	159 ± 3.3	168 ± 2.4	164 ± 1.8	176 ± 1.5	154 ± 1.5	117 ± 1.4
	5	149 ± 2.9	156 ± 2.8	153 ± 2.1	176 ± 1.0	155 ± 1.6	119 ± 2.0
	10	138 ± 1.9	142 ± 2.5	143 ± 2.7	177 ± 1.7	159 ± 0.9	119 ± 1.9
	-5	166 ± 1.3	172 ± 1.1	162 ± 1.6	173 ± 1.4	152 ± 1.9	116 ± 2.0
	-10	167 ± 1.6	172 ± 1.9	155 ± 1.6	162 ± 2.2	134 ± 2.6	109 ± 2.5
138	0	151 ± 3.4	161 ± 2.4	159 ± 2.3	175 ± 2.1	149 ± 2.9	116 ± 2.0
	5	145 ± 2.8	153 ± 1.8	153 ± 2.3	176 ± 1.3	152 ± 2.1	118 ± 2.0
	10	136 ± 1.7	142 ± 2.3	142 ± 2.6	178 ± 1.6	154 ± 2.3	119 ± 1.8
	-5	164 ± 1.9	171 ± 2.5	164 ± 1.8	174 ± 2.0	149 ± 2.8	118 ± 3.0
	-10	165 ± 2.7	172 ± 2.1	159 ± 3.1	163 ± 2.9	140 ± 7.4	111 ± 2.5

B. Speed 3.0 m.p.h.

Cadence	Grade, Degrees	Reference Points: Heel Contact	1	2	3	Toe Lift	4
120	0	162 ± 2.0	171 ± 2.7	161 ± 2.6	175 ± 1.2	153 ± 2.1	116 ± 1.5
	5	151 ± 3.3	158 ± 2.9	154 ± 2.6	176 ± 1.3	154 ± 1.9	118 ± 2.3
	10	138 ± 2.8	144 ± 2.2	142 ± 2.0	176 ± 1.0	155 ± 2.3	117 ± 2.3
	-5	164 ± 3.8	175 ± 1.5	158 ± 2.2	174 ± 1.0	151 ± 3.1	115 ± 2.7
	-10	165 ± 1.7	170 ± 2.0	148 ± 1.7	158 ± 2.6	136 ± 2.0	107 ± 0.8
138	0	158 ± 1.2	167 ± 2.1	161 ± 1.7	176 ± 1.3	153 ± 1.7	116 ± 1.4
	5	145 ± 2.8	154 ± 2.2	151 ± 2.0	176 ± 1.3	155 ± 2.0	117 ± 1.6
	10	134 ± 2.4	141 ± 2.4	141 ± 2.3	175 ± 0.9	156 ± 2.9	117 ± 1.3
	-5	160 ± 3.3	174 ± 1.8	160 ± 2.2	175 ± 0.8	152 ± 2.4	116 ± 2.3
	-10	155 ± 4.2	168 ± 1.9	148 ± 1.7	158 ± 2.8	135 ± 2.0	105 ± 2.4

Reference Points: 1, first extension; 2, flexion during stance (or shock absorption); 3, second extension; and 4, flexion during swing phase.

TABLE 2. EFFECT OF CADENCE AND INCLINATION ON ANKLE ANGLES AT SELECTED POINTS IN WALKING. SEVEN SUBJECTS.

A. Speed 2.5 m.p.h.

		Reference Points					
Cadence	Grade, Degrees	Heel Contact	1	2	Toe Lift	3	4
100	0	102 ± 1.9	104 ± 1.7	83 ± 1.9	106 ± 2.1	113 ± 2.4	95 ± 2.1
	5	100 ± 2.8	100 ± 2.8	81 ± 2.1	107 ± 2.8	114 ± 3.5	95 ± 2.6
	10	95 ± 2.4	96 ± 2.6	79 ± 2.2	111 ± 3.5	115 ± 3.8	95 ± 2.6
	-5	104 ± 2.1	106 ± 2.1	83 ± 2.3	102 ± 1.7	109 ± 2.6	97 ± 1.7
	-10	107 ± 2.6	110 ± 2.8	81 ± 1.7	110 ± 2.8	104 ± 2.2	96 ± 1.1
120	0	101 ± 2.0	103 ± 2.2	84 ± 1.9	104 ± 2.9	109 ± 1.7	97 ± 2.3
	5	97 ± 2.2	98 ± 2.3	80 ± 2.4	106 ± 3.3	112 ± 3.5	95 ± 2.5
	10	95 ± 2.3	96 ± 2.2	79 ± 2.0	108 ± 2.8	113 ± 2.7	95 ± 2.4
	-5	103 ± 2.3	106 ± 2.4	84 ± 2.2	100 ± 1.8	105 ± 1.6	97 ± 1.9
	-10	103 ± 1.9	107 ± 2.4	81 ± 2.9	107 ± 2.4	102 ± 1.7	96 ± 1.3
138	0	99 ± 2.5	101 ± 2.3	83 ± 2.1	103 ± 2.5	110 ± 2.3	97 ± 2.8
	5	95 ± 2.4	95 ± 2.3	80 ± 2.6	103 ± 2.1	108 ± 3.1	94 ± 2.4
	10	92 ± 2.2	92 ± 2.1	79 ± 2.1	106 ± 2.3	109 ± 2.2	92 ± 2.2
	-5	102 ± 2.4	105 ± 2.4	84 ± 2.4	101 ± 1.6	105 ± 2.0	96 ± 2.2
	-10	105 ± 2.7	107 ± 2.8	81 ± 3.6	107 ± 2.8	102 ± 1.2	96 ± 1.3

B. Speed 3.0 m.p.h.

		Reference Points					
Cadence	Grade, Degrees	Heel Contact	1	2	Toe Lift	3	4
120	0	102 ± 2.2	102 ± 3.5	83 ± 2.0	109 ± 2.3	112 ± 3.6	97 ± 2.5
	5	99 ± 1.5	101 ± 1.8	82 ± 1.4	109 ± 2.5	116 ± 2.6	97 ± 1.6
	10	93 ± 1.8	93 ± 2.2	75 ± 3.1	107 ± 2.7	113 ± 1.9	91 ± 1.6
	-5	104 ± 3.4	108 ± 3.7	83 ± 2.8	104 ± 2.6	110 ± 2.7	97 ± 2.2
	-10	103 ± 3.3	105 ± 3.6	79 ± 2.5	99 ± 1.6	103 ± 1.4	94 ± 1.7
138	0	101 ± 1.8	102 ± 2.3	84 ± 0.8	106 ± 2.3	109 ± 2.1	97 ± 2.3
	5	99 ± 0.8	100 ± 1.0	83 ± 1.6	105 ± 1.7	112 ± 1.9	98 ± 1.1
	10	91 ± 1.9	91 ± 2.0	75 ± 3.3	105 ± 2.4	110 ± 2.7	91 ± 1.8
	-5	101 ± 2.9	105 ± 3.0	82 ± 2.7	102 ± 2.6	109 ± 2.2	97 ± 2.3
	-10	101 ± 2.7	103 ± 3.0	79 ± 2.6	98 ± 1.7	101 ± 1.9	93 ± 1.9

Reference Points: 1, first extension; 2, flexion during support phase; 3, second extension; and 4, flexion during swing phase.